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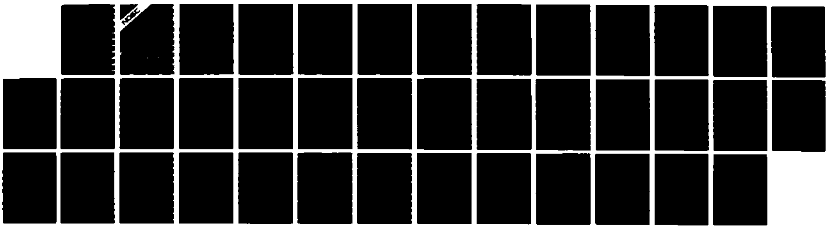

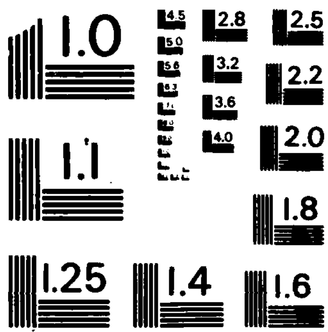

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February 1986

Effects of Extended Camera Baseline and Image Magnification on Target Detection Time and Target Recognition with a Stereoscopic TV System

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Accomplishments of the first year of a two-year investigation of remote presence with a stereoscopic TV display are summarized. A dual-channel video recording and playback system was constructed, consisting of a synchronized pair of optical video disk recorders under computer control, used to record stereoscopic still video frame-pairs in the field and play them back in a controlled laboratory environment for visual performance data collection. Three experiments were conducted to assess the independent effects of camera interaxial separation, image magnification, and their simultaneous interaction on target detection and recognition. The results of these experiments suggested that both image magnification and increases in camera interaxial separation are useful strategies for enhancing visual performance. The interaction of these two factors did not disrupt performance. Recommendations are made for the conduct of subsequent studies and for the design of stereo TV displays for terrestrial reconnaissance applications.

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SUMMARY

OBJECTIVE

Increase the effectiveness of hyperstereoscopic viewing techniques for terrestrial reconnaissance.

RESULTS

1. Both image magnification and increases in camera interaxial separation are useful strategies for enhancing target detection time and recognition rate with stereoscopic TV systems.

2. The interactive effects of image magnification and variable camera interaxial separation were not disruptive of visual performance for remote reconnaissance tasks.

RECOMMENDATIONS

1. Efforts are needed to make visual performance data collection facilities more accessible to large groups of experimental observers and to strictly enforce comparability of images used in visual performance testing.

2. Further research into the effects of hyperstereoscopic viewing techniques on visual performance is indicated. In particular, the U-shaped relationship between camera interaxial separation and target times should be investigated with eye-motion tracking equipment. Also, studies of higher magnifications and wider camera interaxial separations should be undertaken to determine the extremes in both dimensions at which performance breaks down.

CONTENTS

1. INTRODUCTION

The retinal cue for stereopsis consists of small retinal disparities for images of objects which result when we view our surroundings binocularly. Though it is not a prerequisite for adequate perception and performance in many practical real-world situations (e.g., no evidence suggests that stereoblind individuals are any more accident-prone than normals), stereopsis is frequently cited as a powerful cue for accurate spatial vision (Kaufman, 1974). When viewing conditions are poor and monocular cues to depth and distance are degraded or absent, stereopsis helps a viewer discern the form, location, and orientation of objects, and this gives him better control of the environment (e.g., see Pepper, et al., 1981). Several prominent perceptual researchers (i.e., Gregory, 1970; Frisby, 1980) have proposed that the primary adaptive significance of stereopsis lies in the ability to effortlessly differentiate objects from ambiguous surroundings. Stereopsis provides a rapid, automatic anticlutter, anticamouflage mechanism requiring only low-level preconscious processing, freeing cognitive resources for higher level tasks.

STEREOSCOPIC PERCEPTION

Stereoscopic (stereo) TV systems, which are the subject of this report, are simple in basic conception and easily constructed out of widely available hardware, but they pose serious difficulties for operators in many real-world applications (Liebowitz and Sulzer, 1965). Stereoscopic perception under direct-viewing conditions (i.e., those in which observers are physically present in the scene of interest) has been studied scientifically for well over 100 years and remains an active area of investigation among vision researchers, with many central questions remaining unresolved. The far more complex situation of viewing a remote scene through a stereo TV system has been investigated scientifically only in the past two decades and remains only vaguely understood at present. Real-world imagery conveyed by a stereo TV system may be removed from the observer by any distance to which remote video cameras and lines of communication can be extended. What is seen through such systems is frequently unfamiliar and poses substantial perceptual and cognitive challenges for an operator. Further perceptual difficulties occur because stereo TV systems are capable of providing infinite variations in binocular viewing geometries which are unfamiliar because they are simply not possible under direct viewing conditions. For instance, few individuals have practiced interacting with their immediate surroundings while viewing with a wider than normal eye separation (as is possible with a telestereoscope) or through strongly magnifying lenses. Many more individuals have experience with passively viewing distant scenes through binoculars. Viewing with binoculars is a situation in which both eye separation and image magnification are greater than they are with the unaided eye. Even greater deviations from normality are possible and frequently implemented in stereo TV systems. There are no fundamental theoretical obstacles to reproducing the pattern of light stimulation available to an observer at a remote site with a level of fidelity to the infinitely resolved real world that exceeds the human eye's discriminability for detail, intensity, and spectral variations. However, existing imaging systems (video displays, in particular) fall far short of the limits imposed by human vision. Since the inception of TV technology, large-scale efforts have been ongoing to improve the visual-information carrying capacity of video hardware. More recently human factors research

efforts have investigated strategies for displaying less than fully detailed information to human operators in such a way that they can better perceive and more efficiently control occurrences in remotely imaged scenes. This document reports an effort of the latter type.

PRIOR RESEARCH

The available literature on visual performance with hyperstereoscopic TV displays will be reviewed thoroughly in the final report for this project. In the present report brief comments will be presented on a few studies which have a bearing on research methodology with stereo TV displays. In the relevant scientific and technical literature, much has been written on hardware system development, but there is a general scarcity of useful data on visual performance with such systems. Furthermore, conclusions drawn in many available reports are based on flawed assumptions and testing methodologies. Too many display designers, lacking a thorough understanding of the complexity of human performance testing, rely on introspection as their sole means for assessments of perceived spatial relationships in remote scenes. Elsewhere (Spain, 1984), it has been argued that this naive approach confuses the functional with the aesthetic aspects of image quality. Because of this, such an approach fails to provide a sound basis for generalization of findings from the brassboard demonstration model to real-world applications, and it provides no useful information regarding the perceptual processes involved, perceptual cue conflicts affecting visual judgments, and the impact of various viewing system configurations and observer characteristics on either of them.

Over the past two decades, the need to assess visual performance with teleoperators has provided impetus and a focus for investigating stereo TV systems (see Johnsen and Corliss, 1971). Because of the wide range of environments in which teleoperators are expected to function effectively and the variability of human performance with complex man-machine systems, designers of stereo TV displays have conducted only a few adequately controlled experiments to measure the effects of hardware factors, task factors, and human factors on overall system performance (e.g., Fugitt and Uhrich, 1973; Tewell, et al., 1974; Zamarin, 1976; Smith, et al., 1979; Pepper, et al., 1983; Spain, 1984). Unfortunately, hardware, tasks, and human observers have varied so greatly across the few available experimental reports that it is difficult to draw any general conclusions. Not surprisingly, there are no clearly established guidelines as to what hardware parameters impact the performance of what tasks with what types of operators. Only a few researchers have even attempted the more arduous, more fundamental task of clarifying the general nature of space perception through stereo TV systems.

To the best of the author's knowledge, the first systematic comparisons of stereo and monoscopic (mono) TV viewing systems were performed within the nuclear materials processing industries in the late 1940's and throughout the 1950's. Most of the technical reports written at that time did not reach a large readership, and the few reports that were more generally available within the scientific/technical community (e.g., Johnston, Hermanson, and Hull, 1950) provide only subjective impressions as evidence for an advantage of stereo systems for remote manipulation tasks. Advocates for use of stereo TV systems in remote manipulation tasks were seriously challenged by quantitative performance evaluations such as those of Kama and DuMars, who published the first scientific comparison of remote manipulation with a

direct-banded hot cell manipulator under mono and stereo TV viewing conditions in 1964. Their work revealed no statistically significant differences between the two TV viewing conditions for task performance times. In fact, performance times under their mono viewing condition were slightly faster than under the stereo viewing condition. These results led Kama and DuMars to conclude that the added complexity and expense of stereo was not justified in typical remote manipulator applications. Chubb (1964), working out of the same laboratory, performed a follow-up experiment to test the validity of Kama and DuMars' conclusions. Chubb's observers viewed the manipulator work site directly through a plate of glass with and without an eyepatch covering one eye. Manipulation times were significantly faster without the eyepatch for all manipulation tasks tested. Chubb concluded that the discrepancy between his results and those of Kama and DuMars was attributable to the distortion and loss of information by the video system which they had used. In other words, Kama and DuMars may have neglected to provide their observers with an adequately aligned and balanced stereo TV viewing system. Perceptual distortions and visual fatigue resulting from poor display implementation may have washed out any stereo TV advantage. The main point of this discussion is that stereo TV displays must be carefully aligned, balanced, and calibrated prior to performance testing in order to eliminate such biases. Reports that provide only scant details of stereoscopic image collection procedures and display conditions are immediately suspect for this reason.

To date, nearly all investigations of visual performance with stereo TV displays have employed repeated-measures experimental designs, in which each experimental observer is run under each viewing condition tested. Carryover effects are any changes in behavior that occur as a consequence of continued experience with a given task. They constitute a pervasive threat to the validity of any repeated-measures designs and must be dealt with explicitly by the experimenter. Fortunately, acceptable means for controlling them are well known among behavioral researchers (e.g., see Underwood, 1966, pp. 31-40), but they appear to have been largely ignored by many stereo TV researchers. An example is the study by Pesch (1967). In evaluating the relative effectiveness of various manipulator control strategies, he compared manipulative performance between mono and stereo displays on two common undersea salvage tasks — cable handling and precise positioning of an end effector. No differences were found for the end effector positioning task. A significant advantage for stereo TV was found for the cable handling task under degraded viewing conditions on the first day of testing, but no stereo advantage was found on the second day. Pesch interpreted this finding as indicating that any stereo advantage is ephemeral and therefore of only minor practical significance. However, in drawing conclusions from these results one must also consider the fact that his operators repeatedly engaged in a very specific, nonvarying task on two consecutive days, so that the carryover of visual familiarity and visual-motor practice effects could have washed out the initial stereo advantage. Indeed, the stereo advantage which Pesch found on the first day of testing may have considerable practical significance since it is improbable that a remotely operated system deployed on a real-world mission would encounter precisely the same relatively simple conditions and task demands day after day.

A fundamental parameter in stereo TV viewing systems which varies widely throughout the published literature (more often as a result of hardware

constraints than as a matter of conscious experimental design) is camera interaxial separation. When cameras are separated at or near the normal human interpupillary breadth of 63.5 mm (2.5 in.), they capture images with the same disparity values that an on-site observer in the position of the cameras would experience. Orthostereo viewing occurs when camera interaxial separation is 63.5 mm and image magnification through the viewing system is 1.0, which preserves normal textural gradients, relative size, and linear perspective relationships. Reduced interaxial, or hypostereo, views occur when interaxial separations narrower than 63.5 mm are employed. Hyperstereo views result from interaxial separations wider than 63.5 mm. As stated above, the only limitations on how wide a pair of camera viewpoints can be separated is how far they can be physically moved apart. What is more, if images can be recorded, it is possible to use just a single camera and shift its viewpoint to produce stereo images. Thus, as long ago as 1858, the British astronomer Warren de la Rue captured an extraordinary hyperstereo view of the moon, an object approximately 370,000 km distant, many hundreds of thousands of times the normal range of depth perception for orthostereo viewing. At best, the maximum effective range for stereopsis with the unaided eye is only about 450 m (see Graham, 1966, p. 525). By taking a pair of photographs at appropriate times of the year, de la Rue captured a pair of images for which the position of his camera had shifted approximately 30,000 km relative to the moon. His stereogram created an immediate scientific and popular sensation. For the first time in history, human observers could clearly perceive the spherical form of the moon. At the opposite end of the stereo viewing continuum, the most striking application of hypostereo technique involves the taking of stereoscopic scanning electron micrographs (SEMs). Because of their high resolution and excellent depth of field, hypostereo SEMs provide exquisitely detailed three-dimensional views of aspects of the world well below the detail-resolving power and image-fusion range of the unaided eye (see Patterson, 1982 for some good examples of hypostereo images). Both hypostereo and hyperstereo techniques allow us to perceive depth and three-dimensional shapes at scales far smaller or larger than our normal range of visual experience; but both are fundamentally constrained by the limits of stereopsis in the human eye. A detailed discussion of the psychophysical limits of binocular fusion and stereopsis can be found in Ogle (1962).

MILITARY APPLICATIONS

The military purpose of remote terrestrial reconnaissance is to view enemy forces without being seen or at least from a position out of range of hostile fire. This involves viewing across considerable distances, usually beyond the range of target detection and recognition with the unaided eye. Optical gunsights, telescopes, field glasses, and binoculars are standard military equipment items because they extend the range and targeting accuracy of normal human vision. Basically, these devices magnify the images of distant objects and project them onto larger portions of an observer's retinas, enlarging the image to a range of spatial frequencies for which the human visual system is adapted to extract relevant information. Though the user of such a device may not be consciously aware of it, large distortions of textural, density, relative size, and linear perspective cues to depth and distance result. In general, the greater the magnification, the greater the distortion for this important class of visual cues to depth, distance, orientation, and direction. This distortion reportedly becomes much more apparent and distracting to some observers when magnified scenes are viewed stereoscopically (e.g.,

see the comments of Spottiswoode and Spottiswoode, 1953; McAdam, 1954; Lipton, 1982). The effect has generally been attributed to the somewhat vague notion of nonconcordance or conflict between two classes of visual cues — retinal disparities and textural gradients. How such distortions influence perceptual judgments has primarily been studied under monocular or monoscopic viewing conditions in the laboratory with simple stimulus patterns.

As stated, the normal range for stereopsis extends only out to about 450 m for unaided viewing, far short of the distances at which militarily significant objects can be seen with the naked eye. Extending the effective range of stereopsis through a binocular viewing system is both theoretically and practically straightforward. One simply extends the lateral separation between an observer's virtual viewpoints. In addition to providing a 7X to 10X image magnification, most binoculars widen the virtual viewpoints of the observer's eyes to about twice their normal interocular separation by means of prisms. This doubles the disparities of objects within the binoculars' field of view (FOV), consequently doubling the range of effective stereopsis. Larger separations are certainly possible but are constrained by practical considerations of apparatus size, weight, portability, and image stability. Present-day binoculars represent a host of practical compromises which have evolved over centuries of field use (Aldridge, et al., 1975). It would appear that little in the way of controlled visual performance testing (as opposed to routine optical testing) has been conducted to investigate optimal configurations of various interaxial separations for various field applications. Not burdened by the physical constraints imposed by the need for binocular optics, a pair of stereo TV cameras is readily separable by many multiples of the normal binocular interaxial separation, expanding the range of the stereoscopic field to many times the normal range of stereopsis associated with binoculars. The consequences of widening interaxial separation on the retinal pattern of stimulation are predictable on the basis of several geometrical models of stereoscopic transmission through imaging systems (e.g., see Rule, 1939; Spottiswoode and Spottiswoode, 1953; Shields, et al., 1975). Likewise, the effects of image magnification on proximal stimulation are readily predictable by means of geometrical models. What remains largely unresolved and is vitally important to the development of teleoperator viewing systems are the independent perceptual consequences of the image transformations produced by magnification and hyperstereopsis, especially when other artifacts are present in images due to the limited information-transmission capacity of available video systems.

Even less well understood, but probably even more important, are the perceptual consequences of simultaneously varying both interaxial separation and image magnification for a remote reconnaissance task in which three-dimensional targets are set in cluttered real-world backgrounds. The research effort reported herein measured relative performance on two reconnaissance tasks (as measured by target detection time and target recognition rate) under a variety of camera interaxial separations and magnification values. Experiments One and Two were designed to measure the independent effects of camera interaxial separation and magnification on performance. They provide baselines against which the results of Experiment Three can be compared. Experiment Three directly addressed the question of a possible interaction of camera interaxial separation and magnification on both target detection times and recognition rates.

2. METHODS

The procedures and apparatus for this experimentation can be divided into two distinct categories: (1) those used for stereo image collection, and (2) those used for observer screening and performance testing in the laboratory. Stereo image collection was identical for all three experiments. Performance testing procedures varied slightly between experiments.

IMAGE COLLECTION

The experimental design called for the collection of stereo images from a variety of camera interaxial separations crossed with a variety of lens magnifications. Recording was required to ensure comparability of the complex, outdoor imagery used in all presentations across all experimental observers. Repeated playback of the same video frames over the course of testing sessions and across the various observers required that the recorded medium not be degraded by repeated access. Both instrumentation requirements were met by a pair of Panasonic TQ-2023F optical memory disk recorders (OMDRs). The OMDRs provided real-time video recording capability at a resolution higher than that attainable with portable video tape recorders. The OMDRs were genlocked to a set of video cameras by means of a Lenco PSG-311 video sync generator. Figure 1 presents a schematic diagram of the video system used for stereo image collection.

Since outdoor scene conditions constantly change due to factors beyond experimental control, such as variations in winds, cloud cover, sun angle, and movements of self-propelled objects, it was necessary to take a series of stereo picture pairs from varying interaxial separations in rapid succession before conditions in the natural scene changed substantially. This provided

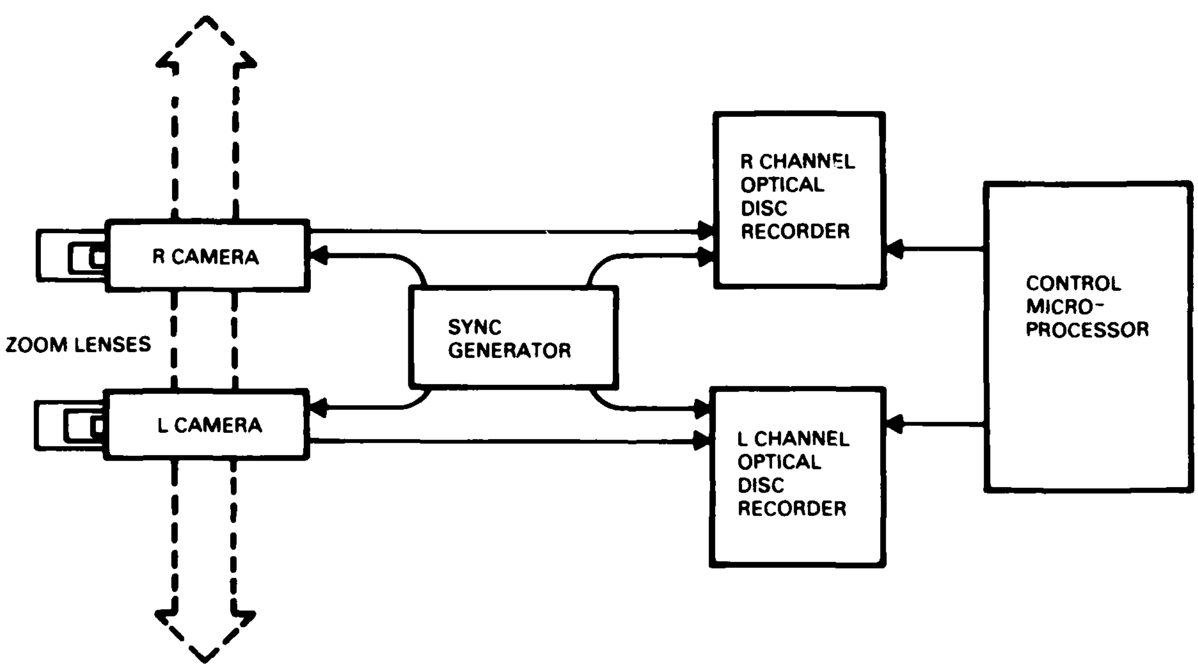

Figure 1. Apparatus for field image collection.

comparability of stereo images for all effects other than interaxial separation, the primary variable of interest. An array of four unequally separated cameras, each with its own pan, tilt, and roll base, was built and level-mounted on a flatbed truck. The camera array was elevated 2 m above ground level during picture taking. Two of the cameras used in the array were Panasonic WV-1800's. The other pair of cameras were RCA TC1005's. Both sets of cameras had identical performance characteristics since both used the same vidicon tube (i.e., the RCA 8541) with similar supporting circuitry. All four cameras were fitted with Vicon 15 mm-225 mm zoom lenses capable of providing a zoom range of from 1X to 12X when used in conjunction with the stereo TV display described below. Cameras encoded relatively high-resolution (>600 TV lines) black-and-white images as measured with a standard EIA resolution chart and the same monochrome monitors used during experimentation. To insure comparability of image brightness and contrast, all four cameras were electronically balanced prior to image collection.

Unequal spacing of the cameras in increasing multiples of the average human interpupillary distance (I = 63.5 mm) provided five distinct left-right interaxial combinations of 2I(127 mm), 4I(254 mm), 6I(381 mm), 10I(635 mm), and 12I(762 mm). At a different time a second set of images was taken with wider interaxial separations of 10I(635 mm), 20I(1270 mm), 30I(1905 mm), 50I(3175 mm), and 60I(3810 mm). By time-multiplexing the video signal outputs from these camera pair combinations to the left- and right-channel OMDRs, five separate stereo views of a scene could be taken in rapid succession. During field image collection, five stereo pairs were initially recorded automatically over a time course of six video frame intervals (i.e., 200 ms), but electronic component failures (and a lack of local replacements for the failed components) forced the adoption of manual switching between the various camera pairs for approximately 80% of all the image pairs acquired. Average time taken to manually switch between all combinations was on the order of 4 s or less.

TARGET-BACKGROUND CONSIDERATIONS

For all three experiments, two different targets were presented for detection and recognition against a cluttered, outdoor background. Only one target was displayed during any target-present trial. The first target was a man standing erect. He was 183 cm tall, 76 cm wide, and 35 cm deep and dressed in Marine camouflage fatigues. (He is hereafter referred to as "the soldier.") A camouflaged M151 jeep, 185 cm(H), by 138 cm(W), by 335 cm(D), was the second target. For all three experiments, equal numbers of trials were displayed in which the soldier or the jeep or no targets were present. In addition, the order of presentation for the soldier, jeep, and no-target trial types was randomized so that there was a .333 probability of presentation for each target type on any given trial. Prior to testing, observers were informed that the order of presentation for trial types would be randomized and therefore unpredictable.

Target position within the display FOV was counterbalanced across trials in a testing session so that observers would not develop positional searching biases during testing. On one-third of the trials for each target type, a target was roughly centered within the left lateral third of the display screen, another one-third of trials had targets roughly centered in the middle third of the screen, and the remaining third had targets roughly centered in

the right third of the screen. In addition, for each target type equal numbers of trials were presented in which linear distance from the cameras to the target was either 200, 400, or 600 m. Angular subtense of targets in the observers' eyes, target dimensions at the display surface, and number of scan lines covering the targets are listed in Table 1.

OBSERVER SCREENING

Experimental observers were obtained through a student services contract with the University of Hawaii's Marine Options program. They were tested in Building 1368, NOSC-Hawaii, and were paid $3.85 per hour for participating. For all experimental observers, the initial session in the laboratory consisted of three distinct components: (1) vision screening and review of visual health history, (2) explanation of the purpose of the experiments and securing informed consent for participation, and (3) familiarization with target detection/recognition testing procedures.

Vision screening consisted of a clinical test of stereopsis with random dot stereograms (Steinfeld's "Stereo Dots Test"), interpupillary distance measurement with a Bausch & Lomb P-D Gauge, the CARDS test of ocular sighting dominance (Coren and Kaplan, 1973), as well as measurements of vertical and lateral phorias, monocular and binocular Snellen chart far acuities, and stereoacuity (i.e., the "Depth Test" taken with an Armed Forces Vision Tester (AFVT). Two of the nine candidate observers who were screened were rejected from further testing. One scored significantly below average on both the Stereo Dots Test and the AFVT Depth test, suggesting a stereoanomaly. The other rejected candidate had difficulty with all tests involving perception of fine detail, probably due to an uncorrected myopia. Monocular and binocular acuities were measured at greater than 20/40 (.5) for this candidate. Results of the screening procedure for observers who went on to participate in the experiments are summarized in Table 2.

Three experimental observers were females, and four were males. Two wore eyeglasses and one wore contact lenses throughout the testing sessions. Average age was 24.0 years (s.d. = 4.24 years), and average interpupillary distance (IPD) was 62.86 mm (s.d. = 3.75 mm). All observers were within normal range for Snellen acuities, phorias, and measures of stereopsis. All were right-eye-sighting dominant. Following successful completion of the screening procedure, observers filled out a vision history questionnaire (see Appendix A). In their responses to the questionnaire, six of the seven observers reported no history of organic eye disease or dysfunction. One (DG) reported problems with convergent strabismus (i.e., cross-eyedness) in childhood, which had been corrected with prescriptive lenses and eye exercises. This same observer was the only one to report frequent headaches (i.e., three per week on average) but also reported that these had no effect on ability to see clearly. This observer was allowed to participate in the experiments because all vision screening measures taken were within the normal range.

Next, observers were given a written and verbal explanation of the series of experiments to be conducted (see Appendix B) and their written consent to participate was secured. Following this, they were seated in the testing chamber and presented a brief video "slide show" which introduced them to general test procedures and also displayed examples of various target/position/distance combinations in both stereo and mono display modes.

Table 1. Displayed Width, Scan Lines, and Retinal Subtense of Soldier and Jeep Targets.

SOLDIER

Magnifications for the Three Target Ranges	Displayed Width, mm	Active Scan Lines	Retinal Subtense, arcmin
200 meters			
1X	1.8	8	12.5
1.25X	2.3	10	15.9
2X	3.8	16	25.9
4X	7.6	33	52.1
8X	15.2	66	104.2
400 meters			
1X	0.9	4	6.3
1.25X	1.2	5	8.0
2X	1.9	8	12.9
4X	3.8	16	26.1
8X	7.6	33	52.1
600 meters			
1X	0.6	2	4.2
1.25X	0.8	3	5.3
2X	1.3	5	8.6
4X	2.5	11	17.4
8X	5.1	22	34.7

JEEP

Magnifications for the Three Target Ranges	Displayed Width, mm	Active Scan Lines	Retinal Subtense, arcmin
200 meters			
1X	3.3	8	22.7
1.25X	4.2	10	28.9
2X	6.8	16	47.0
4X	13.8	33	94.6
8X	27.6	67	189.3
400 meters			
1X	1.7	4	11.4
1.25X	2.1	5	14.4
2X	3.4	8	23.5
4X	6.9	16	47.3
8X	13.8	33	94.6
600 meters			
1X	1.1	2	7.6
1.25X	1.4	3	9.6
2X	2.3	5	15.7
4X	4.6	11	31.5
8X	9.2	22	63.1

Table 2. Summary of Visual Screening Procedures for Experimental Observers.

OBSERVER	SEX	AGE	IPD, mm	STEREO DOTS TEST	FAR ACUITY			DEPTH TEST
					BINOCULAR	LEFT EYE	RIGHT EYE	STEREOACUITY, in.
SS	M	19	66.0	100%	1.0(20/20)	0.8(20/25)	0.8(20/25)	10
RM	F	27	59.5	100%	1.33(20/15)	1.0(20/20)	1.18(20/17)	10
RN	M	19	65.0	92%*	1.33(20/15)	1.0(20/20)	1.18(20/17)	20
SW	M	27	65.5	100%	1.66(20/12)	1.66(20/12)	1.00(20/20)	10
KL	M	24	65.0	92%*	1.18(20/17)	1.18(20/17)	0.8(20/25)	10
RC	F	22	63.0	100%	1.18(20/17)	1.18(20/17)	1.0(20/20)	20
DG	F	30	56.0	100%	1.33(20/15)	1.33(20/15)	1.33(20/15)	10

Note: No Observers were found to have deviant vertical or horizontal phorias, and all were right-eye-sighting dominant.

Next, observers were given 90 trials of practice with the response keys. The procedure was identical to the general trial procedure detailed below except that the frames presented were not natural imagery but text, with XXX's, OOO's, and blank fields serving as three simple frame types. Finally, observers were given 90 practice trials with the same types of natural images used during experimental sessions.

VISUAL PERFORMANCE TESTING PROCEDURE

The apparatus and procedure involved in a single trial were identical for all trials in all three experiments. A description of these will now be presented, followed by a description of the design and overall testing procedures used in the screening session and the three experiments.

Figure 2 presents a schematic diagram of the video system used to display stereo images. Both two-dimensional and three-dimensional images were presented to observers by means of a bench-mounted polarizer stereo TV display of the type frequently used in stereo TV experiments (see Cole, Pepper, and Pinz, 1981, for a detailed description and illustration). Stereoscopic images were presented by playing back the right-channel OMDR's frame to the right-channel monitor and the left-channel OMDR's frame to the left-channel monitor. Monoscopic images were presented by playing back the left-channel OMDR's frame to both left- and right-channel monitors. A pair of Panasonic WV-5470 17-inch diagonal black-and-white TV monitor screens were positioned orthogonally, with a 40/40 beamsplitter bisecting the angle between them. Polaroid HN38 linear polarizing filters were used in the viewing hood and immediately in front of

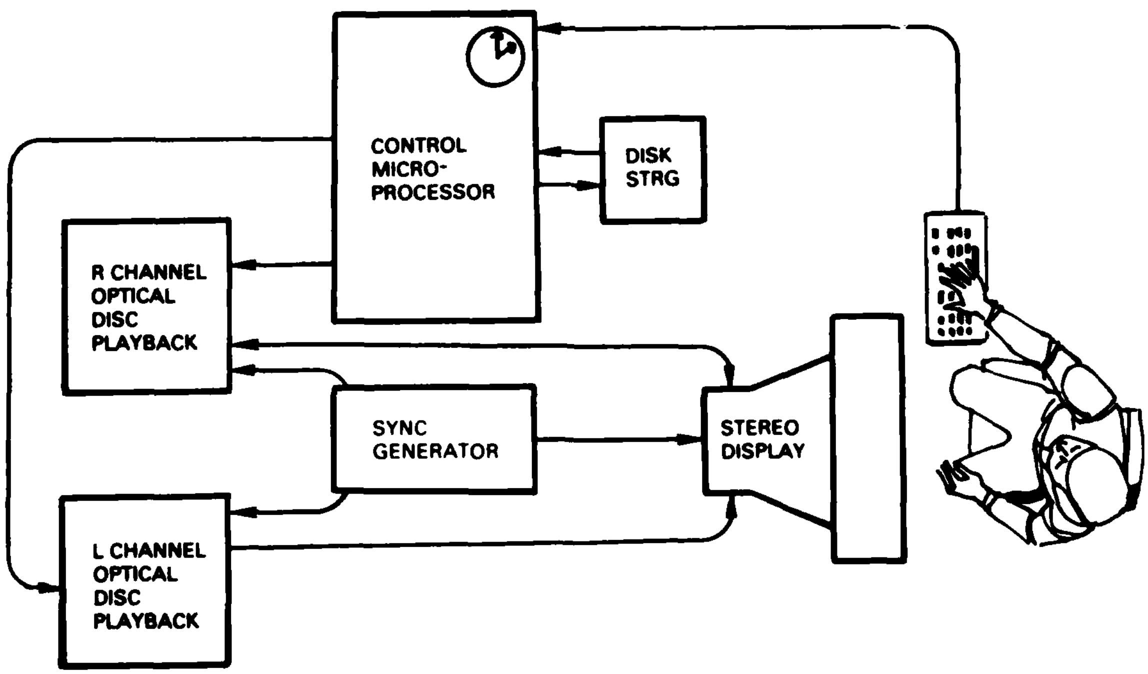

Figure 2. Apparatus for data collection.

the display CRT screens to provide stereoscopic channel separation. Monitor intensity and contrast were balanced subjectively prior to each day's testing, with average luminance available at the observer's position equal to approximately 35 cd/m^2. An observer was seated in front of the display in a darkened, windowless 1.5- by 2.1-m (5-ft by 7-ft) room with the index and middle fingers of the right hand resting on a pair of high-speed telegraph keys (Archer #201084) and the right foot resting on a foot pedal (Linemaster foot switch #632-S). Head position and polarizing filter orientation were constrained by use of a viewing hood. This viewing hood also masked out the observer's peripheral FOV. Eye-to-display screen distance was fixed at 0.5 m. In addition to holding linear polarizing filters in the proper orientation for stereo channel separation, the viewing hood held +0.5 diopter lenses in the optical pathway of both eyes for approximate collimation of the screen images.

At the beginning of each trial, a video frame was displayed in which the word "READY" was centered on the screen at screen depth (i.e., with zero disparity). This was the observer's cue to start the trial sequence, whenever he or she was prepared to do so, by tapping the foot pedal. A randomly variable delay of from 0.5 to 1.5 s followed the foot tap; then the response-time clock was started simultaneously with onset of a predetermined video frame. The observer tapped either or both of the telegraph keys upon detecting any target in the scene. Elapsed time between stimulus onset and observer response was recorded as target detection time. Immediately following the key tap, the words "MAN" and "JEEP" were displayed centered on the display at screen depth. This prompted the observer to indicate which target was present in the scene by tapping the left (index finger) telegraph key to indicate the soldier and the right (middle finger) key to indicate the jeep. The target recognition response was not timed, but it was scored for correctness. For trials in which no target was presented, the observer was instructed to refrain from tapping the telegraph keys. On these blank trials, 4 s elapsed before the scene display was terminated and a "NO TARGET" response was automatically recorded. Immediately following the observer's response or the 4-s interval indicating that there was no target, a frame indicating whether the response was either "CORRECT" or "WRONG" was displayed for 1 s prior to the "READY" message indicating the beginning of the next trial.

Experiment One was designed to investigate the main effect of camera interaxial separation on target detection times and recognition rates. Interaxial separations employed in this experiment were 2I(130 mm), 5I(317.5 mm), 8I(508 mm), 10I(635 mm), and 30I(1905 mm). Display FOV remained fixed at the orthoscopic value (i.e., 40 deg), which provided normal perspective and relative size cues for depth and distance. Target distance (200, 400, and 600 m) and position in the display field (left, center, and right) were counterbalanced across interaxial separations. Observers participated in three approximately 100-min sessions held on separate days. Each session consisted of 4 blocks of 135 trials for a total of 540 trials with about a 2-min break between blocks.

Experiment Two was designed to investigate the main effect of camera FOV on target detection times and recognition rates. Lens magnifications providing FOVs of 40, 32, 20, 10, and 5 deg were employed. Camera interaxial separation was held constant at 2I(130 mm) for all stereo views. Target distance and position in the display FOV were counterbalanced across the five FOVs employed.

Both stereo and mono views were shown for each scene employed. Observers participated in two sessions of approximately 90 min each. These sessions were held on separate days. Each session consisted of 3 blocks of 192 trials for a total of 576 trials. Observers were allowed about a 2-min break between blocks.

Experiment Three investigated the separate and interactive effects of camera interaxial separation and display magnification on target detection times and recognition rates. Interaxial separations of 2I(130 mm), 4I(260 mm), 6I(390 mm), 10I(1300 mm), and 12I(1560 mm) were fully crossed with magnifications of 1X(40 deg), 1.25X(32 deg), 2X(20 deg), and 4X(10 deg). Target distance and position in the display FOV were balanced across the various combinations of camera interaxial separation and magnification. Each observer participated in three sessions of approximately 90 min each. Sessions were held on separate days, and each session consisted of 2 blocks of 240 trials for a total of 480 trials. Observers were allowed about a 3-min break between blocks of trials.

3. RESULTS

In this section, the results of the experiments are reported individually. Each of the three experiments provided two distinct sets of data for statistical analysis — target detection times and target recognition rates. Target detection times were calculated by averaging response times for all trials within a treatment condition, excluding trials in which unacceptable responses were made or for which the observer made no key-press response. Target recognition rates were calculated by dividing total correct responses in a treatment condition by the total number of valid trials within that condition. Each of these dependent measures was subjected to its own repeated-measures analysis of variance (ANOVA). A statistical significance level of $p < .05$ was set a priori for all effects in all analyses. Conservative statistical procedures were used throughout in an attempt to hold Type I errors (i.e., false positive effects) to less than the stated significance level. When statistical assumptions underlying the ANOVAs were not strictly adhered to (primarily because of the small sample size), corrections to the degrees of freedom in F-tests were made in the form of the Huynh-Feldt (1976) procedure. Testing for effects among various cell means subsequent to the ANOVAs was performed with the Newman-Keuls procedure (Newman, 1939).

EXPERIMENT ONE

Table B-1 presents the ANOVA source table for target detection times in Experiment One. All significant effects in the analysis are reported below. As is typically the case in studies of visual performance, there was a large individual-differences effect [$F(1,4) = 336.1$, $p < .01$] among the the five observers participating in this experiment. The main effect of camera interaxial separation was statistically significant [$F(4,16) = 5.83$, $p < .01$]. Mean values and standard deviations for the five values of interaxial separation are plotted in Figure 3. Except for the strongly anomalous data point for the 10I(635 mm) camera separation, the curve plotted in Figure 3 reflects a gradual shortening of target detection times with increasing camera separations out to the maximum separation tested (i.e., 30I, or 1905 mm). Comparisons among the various treatment means for this effect revealed

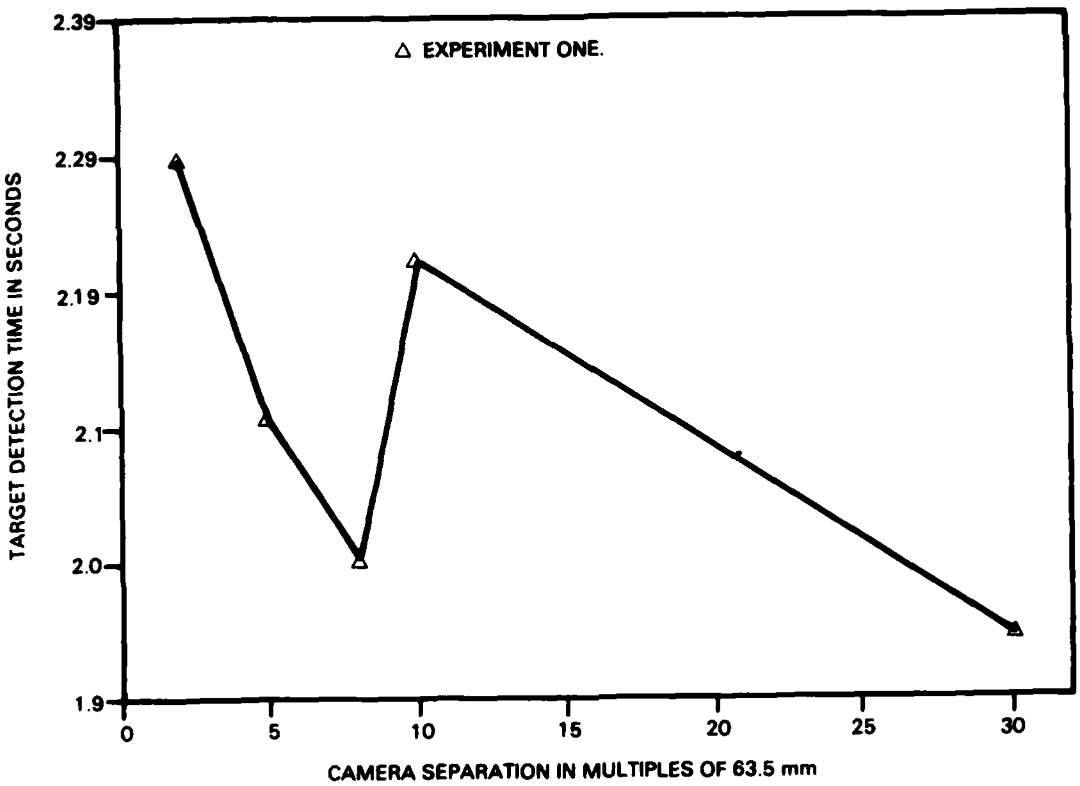

Figure 3. Effect of camera separation on detection time.

significant differences ($p < .05$) between the 2I(130 mm) camera separation and all other separations, except the anomalous point for 10I(635 mm). The anomalous point was also found to be statistically different from its two immediately neighboring points.

Effects similar to those found for target detection times were found for target recognition accuracy. Table B-2 presents the ANOVA source table for target recognition rates in Experiment One. A significant main effect for camera separation [$F(4,16) = 11.04$, $p < .01$] is plotted in Figure 4. Once again, an anomalous point which was significantly different from both of its immediate neighbors was found at the 10I(635 mm) camera separation condition. Excluding this point from consideration, the plot reveals that recognition rates increased with increasing camera separation out to the maximum value tested. A significant improvement in recognition accuracy was found in the transition from 2I(130 mm) to 8I(508 mm), but no significant difference was found in the transition from 8I(508 mm) to 30I(1905 mm).

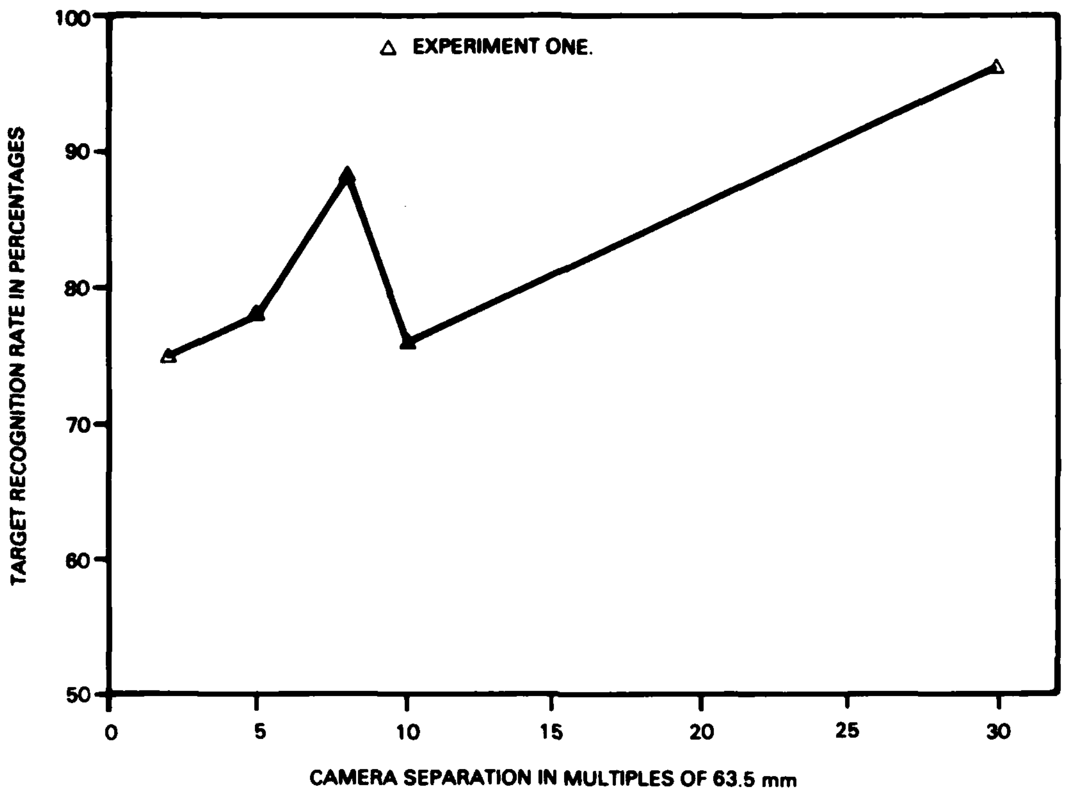

Figure 4. Effect of camera separation on recognition rate.

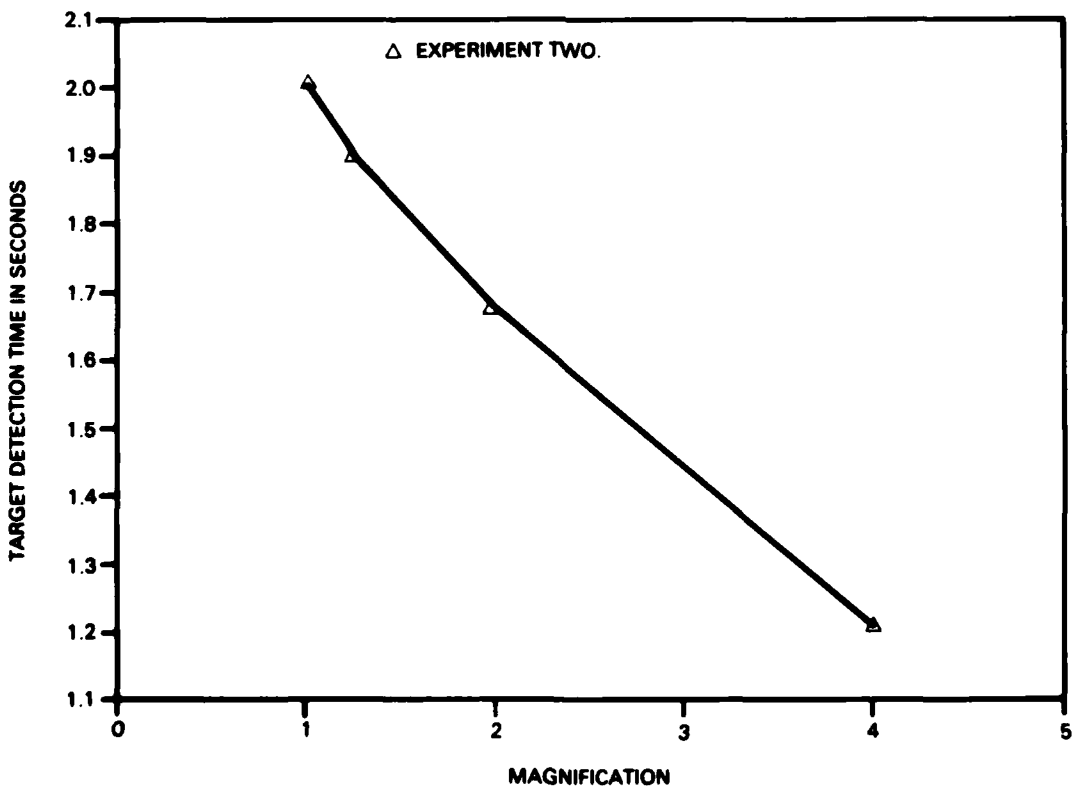

Figure 5. Effect of magnification on detection time.

EXPERIMENT TWO

Table B-3 presents the ANOVA source table for target detection times in Experiment Two. Again, there were large individual differences between the five observers participating in the experiment. The main effect of magnification was significant [$F(3,12) = 12.19$, $p < .05$], as was the main effect for the stereo/mono comparison [$F(1,4) = 10.26$, $p < .05$]. The main effect of magnification on target detection time is plotted in Figure 5.

Table B-4 presents the ANOVA source table for the analysis of recognition rate data from Experiment Two. The significant main effect for magnification [$F(3,12) = 7.52$, $p < .05$] is plotted in Figure 6. A significant interaction between magnification and the stereo/mono viewing condition [$F(3,12) = 22.1$, $p < .01$] is plotted in Figure 7.

EXPERIMENT THREE

Table B-5 presents the ANOVA source table for target detection times in Experiment Three. As in Experiments One and Two, which employed five of the seven observers who participated in Experiment Three, there were large individual differences between observers. The main effect of camera inter-axial separation on target detection times is plotted in Figure 8. This effect was found to be statistically significant [$F(4,20) = 3.41$, $p < .05$]. The plot in Figure 8 reveals an interesting relationship between camera separation and response time which is contrary to the effect found in Experiment One (see Figure 3). A significant main effect for magnification [$F(3,15) = 20.0$, $p < .01$] on target detection time is plotted in Figure 9. In comparing Figure 9 with data from Experiment Two (plotted in Figure 5), one notes a large discrepancy in the overall pattern of performance, which is most apparent at the 2.0X magnification level. Whereas there is a simple linear effect of magnification out to 4.0X on response time in Experiment Two, there was a steep falloff in response time to an apparent asymptotic level by 2.0X in Experiment Three. No significant interaction between camera interaxial separation and magnification was found for target detection time.

The ANOVA source table for effects of camera interaxial separation and magnification on target recognition rates in Experiment Three is reported in Table B-6. A significant main effect for camera separation on target recognition rate [$F = (4,24) = 19.39$, $p < .01$] is plotted in Figure 10. The significant main effect of magnification [$F(3,18) = 71.12$, $p < .01$] on target recognition rate is plotted in Figure 11. More importantly, a significant interaction [$F(12,72) = 4.98$, $p < .05$] between camera interaxial separation and magnification was found for target recognition rate. This interaction is plotted in Figure 12.

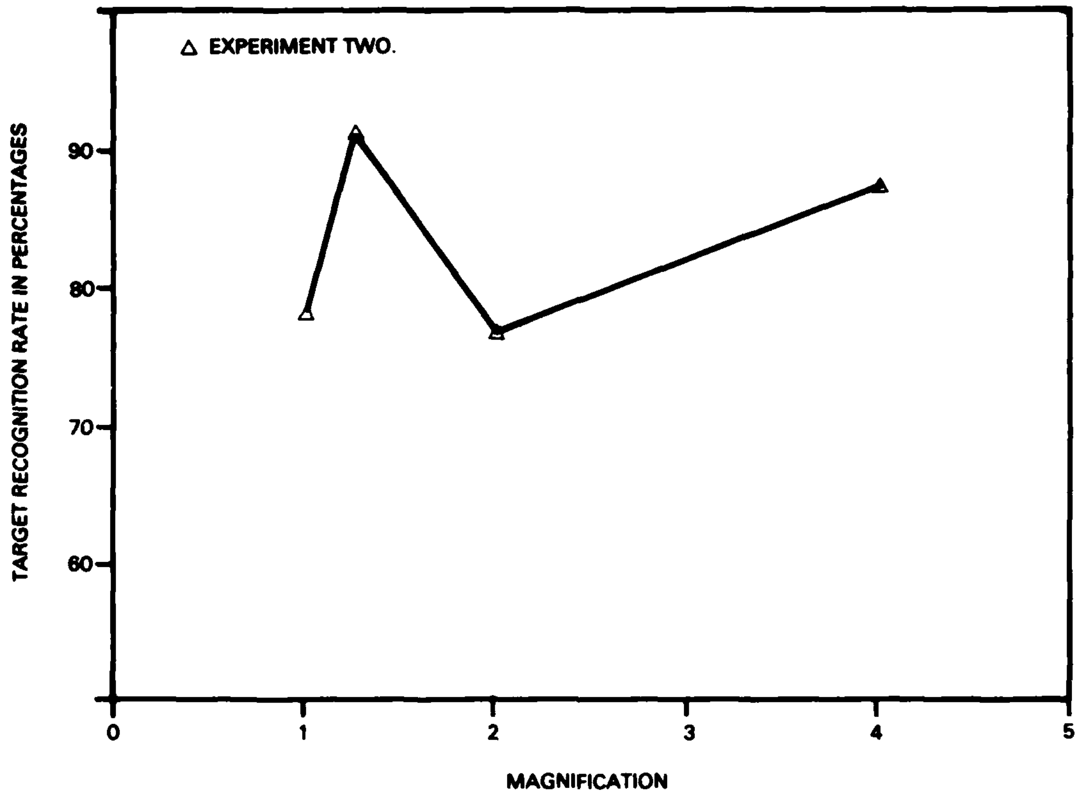

Figure 6. Effect of magnification on recognition rate.

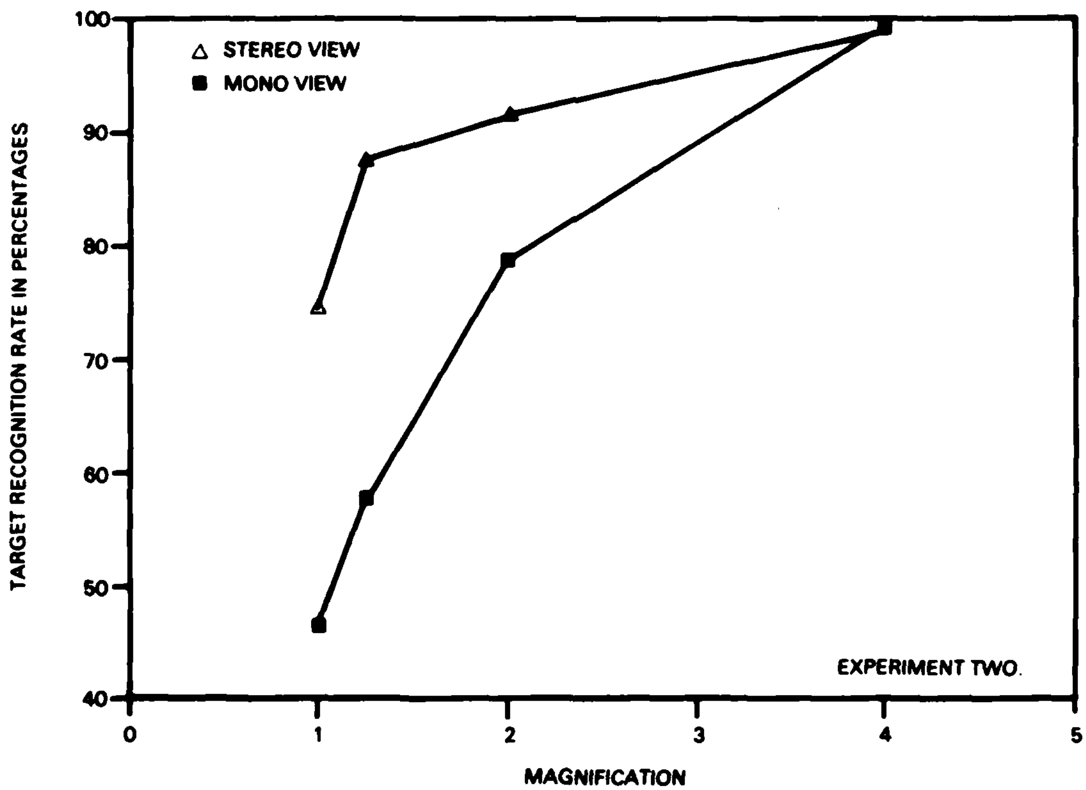

Figure 7. Effect of interaction on recognition rate.

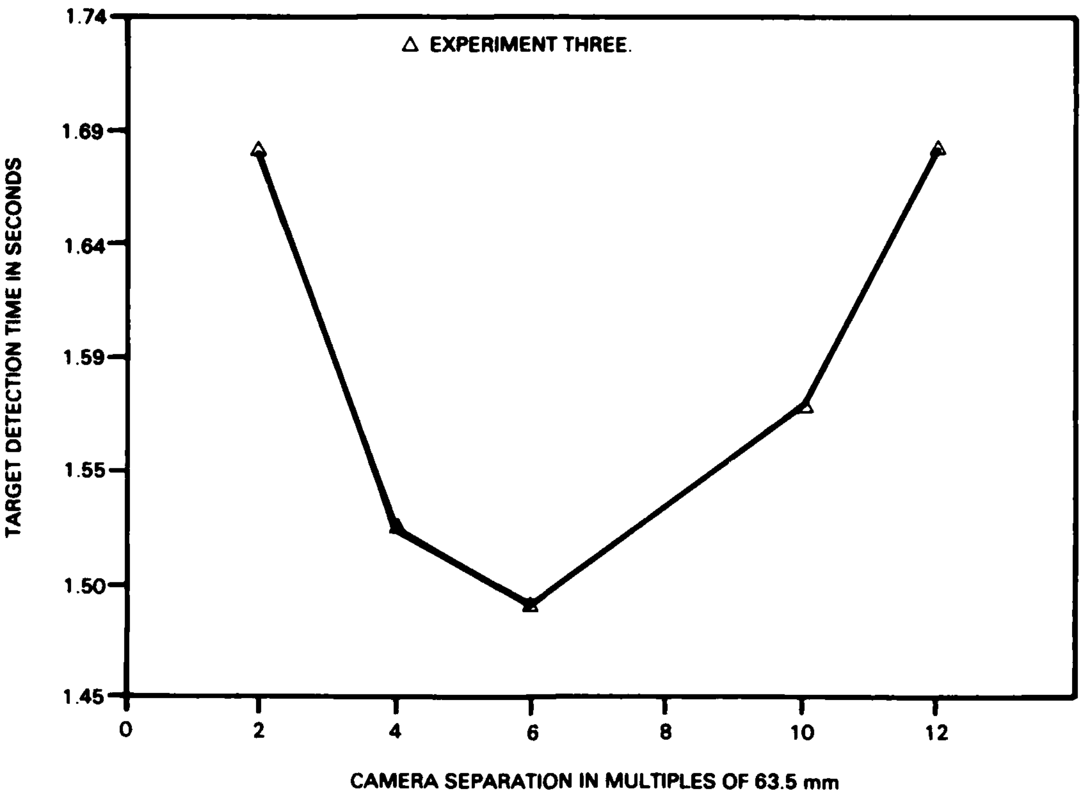

Figure 8. Effect of camera separation on detection time.

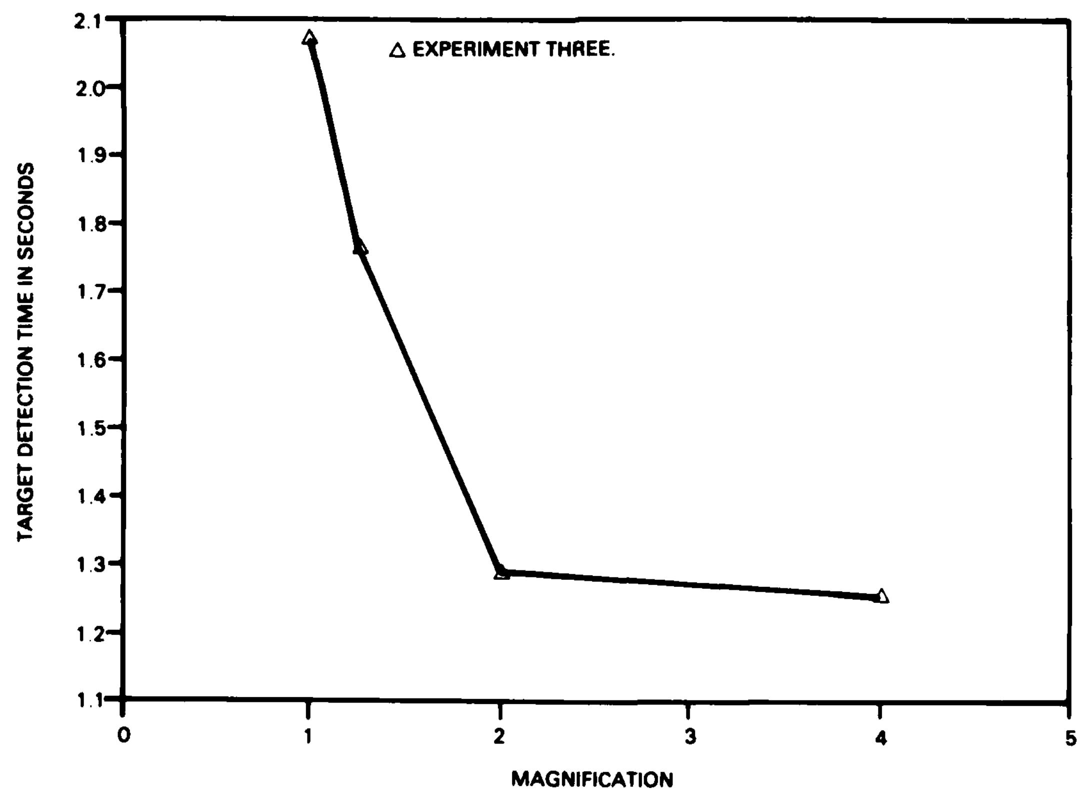

Figure 9. Effect of magnification on detection time.

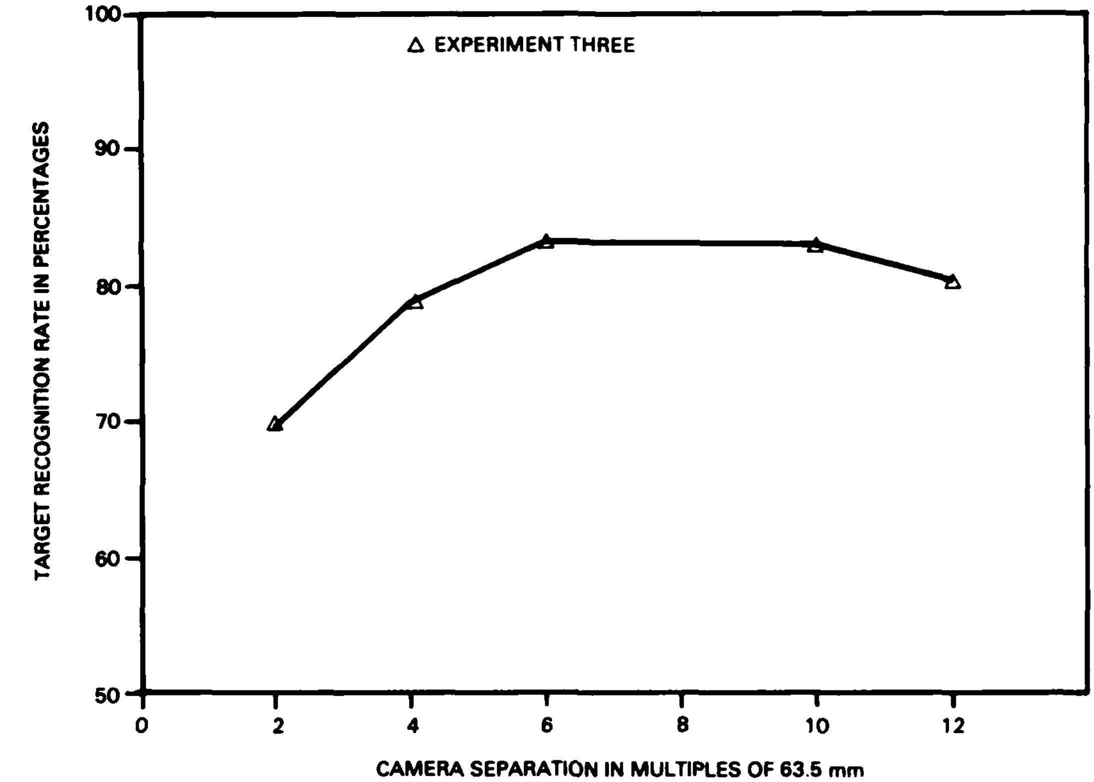

Figure 10. Effect of camera separation on recognition rate.

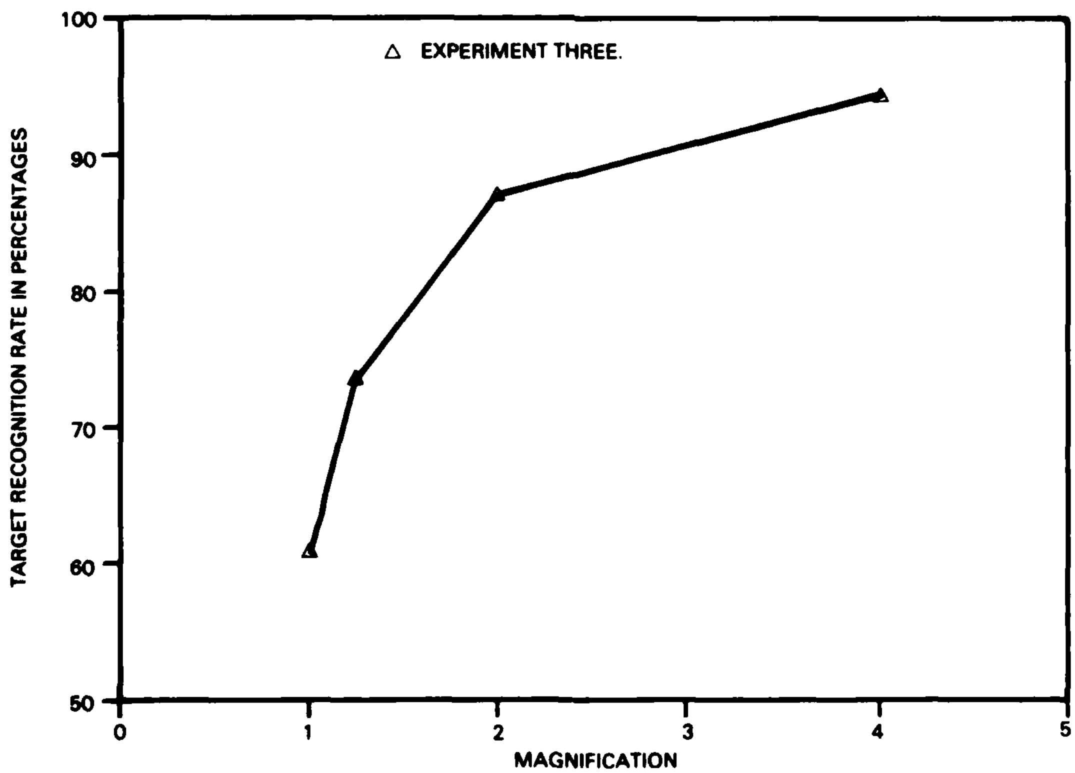

Figure 11. Effect of magnification on recognition rate.

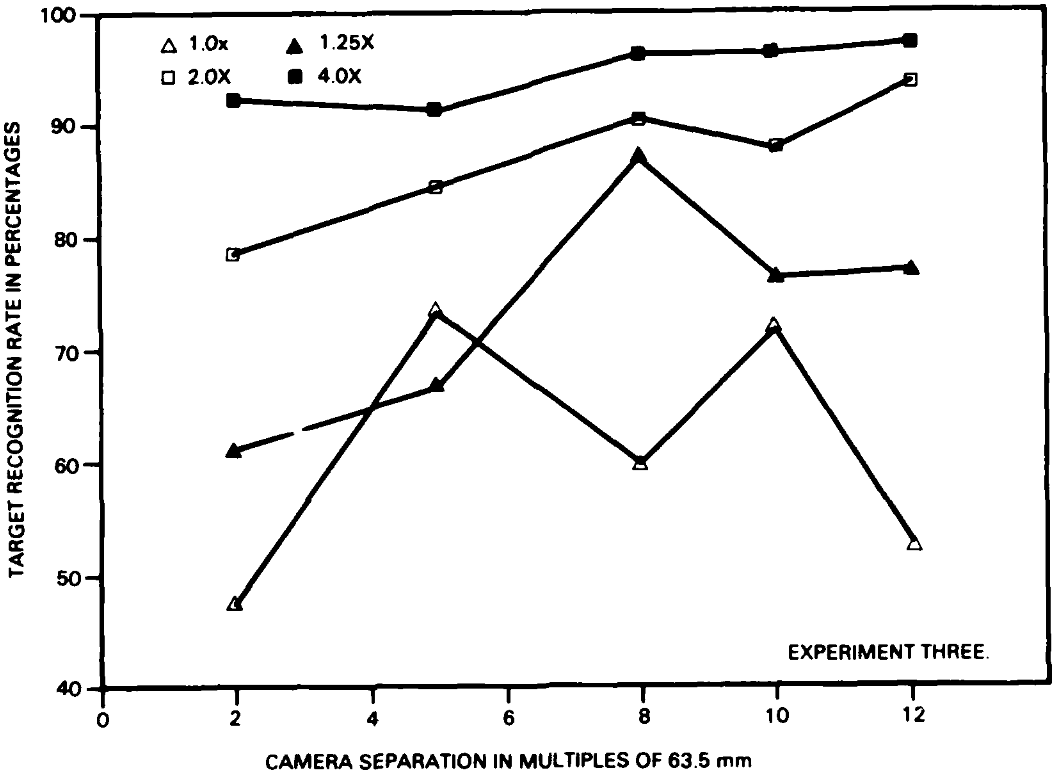

Figure 12. Effect of interaction of camera separation and magnification on recognition rate.

4. DISCUSSION AND RECOMMENDATIONS

The series of three experiments reported in this document was carried out in order to assess the independent and interactive effects of camera interaxial separation and image magnification on target detection and recognition under real-world viewing conditions by means of available, off-the-shelf video technology. Experiments were performed in a progressive fashion, with single-factor designs for each of the main variables of interest (i.e., Experiments One and Two) being run prior to the ultimate design of interest (Experiment Three), in which interactive effects on visual performance could be assessed. In this way, observers were well familiarized with testing procedures and stimulus materials prior to participating in Experiment Three, and the systematic replication of patterns of performance across experiments could lend validity and credence to results and conclusions of the series (Sheridan, 1976, p.105). Unfortunately, Experiment Three did not provide a very satisfying replication of the pattern of results found in Experiments One and Two, and this general weakness in the consistency of results across experiments makes it difficult to interpret the results of all experiments. Therefore, prior to presenting a qualified account of the patterns of performance found in the three experiments, a brief discussion of some of the methodological improvements which could be made in future research efforts of this type will be presented.

All three experiments suffered from lack of an adequate observer sample. This did not present a serious problem for earlier experiments performed at NOSC (i.e., Smith, et al., 1979; Pepper, et al., 1981; Pepper, et al., 1983; Spain, 1984) since all those experiments were carried out using relatively simple stimulus patterns, primarily depth resolution judgments with two- or three-rod Howard-Dolman apparatuses. Without a sufficiently large sample of observers, it is extremely difficult to obtain stable estimates of performance, particularly when the tasks which observers are required to perform are complexly influenced by a multitude of visual factors, as they undoubtedly were in the present series of experiments. For statistical reasons alone, the small sample size made it impossible to analyze some of the factors, such as target type and target position, in the display field which were explicitly controlled in the designs of all experiments. This, in effect, forced the rejection of potentially explained variation in the analyses. The problem of inadequate observer sample size stems from the fact that taking part in such studies as an observer is a task requiring three to five sessions of only 1 to 2 hours each per experiment. NOSC-Hawaii personnel are a generally busy group, and even though they have convenient access to the existing test site, very few have the time, on a regular basis, to participate in such activities. Another means of acquiring observers is through on-station private contracting firms, but such arrangements have proven relatively expensive in the past and have generally not been able to provide more than four or five observers. Yet another means of acquiring observers is through the existing student services contract with the University of Hawaii. This was, of course, the means by which observers were provided for the present series of experiments. The greatest problem with this arrangement is that the University is more than 20 miles distant from NOSC-Hawaii, and student contractors are understandably reluctant to make the trip for only 1 or 2 hours of work. A solution to this problem which is currently being pursued is the possibility of establishing a testing facility on the main campus of the University of Hawaii. This would be done in collaboration with individuals and groups within the University who are interested in establishing a center for high-technology research which encompasses academic, industrial, and governmental efforts. Such an arrangement would provide easy access to a performance-data collection facility for many thousands of potential participants each school day. Plans and proposals are being prepared jointly with Dr. Robert E. Cole of the University of Hawaii Psychology Department to establish such a facility.

Another probable source of difficulty in interpreting the results of the present series of experiments arises from the complexity and ever-changing nature of the real-world scenes which were collected for use as stimulus patterns. As explained in Section 2, close comparability of images across a range of camera separations was assured by taking a series of variable stereo baseline pairs in rapid succession, before lighting and the positioning of objects in the scene could change substantially. This technique makes direct comparisons among the various camera interaxial separations possible. However, it only ensures comparability across a range of camera separations which are unique for a particular target in a particular scene, at a particular distance from the cameras, in a particular position within the FOV, and at a particular magnification. If any of these controlled viewing factors were to change, so too could the incompletely controlled factors of scene lighting and the positioning of nontarget objects within the scene. Changes in scene lighting affect not only a target's brightness and the amount

of surface detail available at the display, but also the contrast of a target with its background. Efforts were made during the image collection phase of the project to avoid taking stereo pairs when lighting differed substantially from roughly even overhead sunlight. Image pairs were collected during midday from 1000 to 1530 hours during the months of June and July. Image taking was suspended when clouds shadowed any portion of the target range. Each of the more than 6000 video frames collected was reviewed and graded for image quality, with only the highest quality image pairs being used in the experiments. It was our initial expectation that these precautions would provide sufficient comparability of images across the range of controlled viewing factors listed above, but the empirical results of the experiments may suggest otherwise. Inconsistencies in results of the three experiments suggest that more rigorous controls are required for future work in order to ensure closer comparability of scene content and image quality for all combinations of viewing conditions sampled.

One means of accomplishing this which is currently being pursued involves extensive use of digital image processing techniques. In particular, a series of empty (i.e., targetless) scenes could be captured in stereo from a variety of camera interaxial separations and magnification values in much the same manner used for the present series of experiments, except that far fewer images would be taken, and more time and effort could be devoted to enforcing stricter photometric comparability across images. When a suitable set of images are collected, selected for comparability, and digitized, they would serve as the backgrounds onto which target shapes would be superimposed at various positions in the scenes. Pixel accurate positioning could be accomplished in three dimensions. Disparities for targets which are manifested as lateral position shifts between the left- and right-channel images would be simulated in accordance with Spottiswoode and Spottiswoode's (1953) geometrical model of stereo transmission. In this fashion, the complexity of real-world scenery would be maintained in the test stimuli while rigorous control of target brightness and contrast could be maintained across the various viewing conditions tested.

Now that the main sources of difficulty in interpreting results have been discussed and means for their elimination suggested, an assessment can be made of the conclusions derivable from the study despite the methodological problems encountered. First of all, he effects of image magnification on performance generally correspond well with those reported in the available literature on target acquisition with TV displays (e.g., see Erickson, 1978). Results of Experiments Two and Three demonstrate that increasing the magnification of the TV viewing system, thereby increasing the dimensions of targets at the display and the number of active scan lines of which they are composed (see Table 1), decreases the amount of time required to detect the presence of targets. Mag- nification also greatly enhances the rate of target recognition across the somewhat restricted range of values tested in Experiments Two and Three (i.e., 1.0X to 4.0X). These results are not surprising. They are also found under monoscopic and direct viewing conditions. In general, up to size limits that exceed the dimensions of conventional stereo TV display screens, the larger the image of an object on the retinas of an observer, the more defined it is in terms of pixels or scan lines, and the more quickly and accurately it will be recognized by an observer. Optical magnification is a desirable character- istic of remote TV reconnaissance systems since it affords the operator essentially the same advantages it does an on-site human

observer equipped with a pair of binoculars. He can see more effectively over long distances, which also makes it more difficult for him to be seen by opposing forces. Magnification, however, narrows the effective area which can be scanned at any given moment. It also places increased demands on the means by which remote cameras are aligned and aimed. Any inaccuracies in aligning cameras are multiplied by magnification. This is particularly serious in the case of vertical misalignments in stereo TV images, where even small (i.e., <10 arcmin) misalignments are known to result in discomfort and perceptual distortions (Farrell and Booth, 1975). Additionally, any unintended movement or tremors in the remote camera configuration are increased in magnitude and made more apparent and distracting to an observer. It should be kept in mind that the present line of investigation avoided such difficulties by using only preselected, well-aligned static pictures that sampled performance over only a moderate range of magnification values. The success of magnification strategies with movable cameras, particularly those which have their movements coupled to the head and upper body motions of a remote operator, will depend greatly on the elimination of such misalignment problems.

Results from Experiments One and Three regarding the effects of hyperstereo viewing on performance were less clear. Ignoring the anomalous datapoint measured in Experiment One for the 10I(635 mm) camera interaxial separation, detection time decreased and recognition rate increased with increasing camera interaxial separation out to the widest separations tested in Experiments One and Three. This essentially replicates the pattern of performance which we have generally found to hold in previous laboratory studies (Pepper, et al., 1981; Spain, et al., 1982; Pepper, et al., 1983; and Spain, 1984) using simpler stimulus patterns and tasks. One of the main questions raised by these earlier studies was whether this general pattern of performance would hold when other information-rich classes of perceptual information which are frequently present in real-world scenes (e.g., textural gradients, interposition, relative size and height in the FOV, and linear perspective) exert a moderating influence on performance. Results from Experiment Three did not correspond closely with those found in Experiment One, and they did not replicate the pattern of results from earlier investigations. Instead, for both dependent measures employed in Experiment Three, performance appeared to be optimized at an intermediate camera separation, i.e., at 6I(381 mm), and it actually fell off with increases in camera separation beyond this level. The effect was more apparent in the target detection time measure, but it was also found for recognition rate. At this point, these results remain somewhat puzzling and therefore require further experimental investigation before firm conclusions are warranted.

The significant interactive effect between camera interaxial separation and magnification that was found for target recognition rate in Experiment Three suggests that at the higher levels of magnification (i.e., 2.0X and 4.0X) tested, the pattern of increasing efficiency for wider camera separations generally held. However, at the lower magnification levels (i.e., 1.0X and 1.25X), recognition rates were generally much poorer, and performance across the varying levels of camera interaxial separation was more erratic. This pattern of results does not confirm the impressions of stereo photography purists (e.g., McAdam, 1954), who claim that bizarre distortions of space perception result from nonorthoscopic combinations of camera interaxial separation and magnification or, at very least, that if such distortions do

occur, they do not have disruptive consequences for target detection and recognition.

In summary, the results of experiments conducted in the first year of the Video Hyperstereo Viewing project support the following recommendations:

1. Because of the ever-changing nature of outdoor scenes, further efforts should concentrate on strictly enforcing comparability of image brightness, target-background contrast, and scene content across all viewing conditions tested. Digital image processing is suggested as a practical means of providing image comparability.

2. Due to difficulties in attracting and maintaining sufficiently large groups of observers in our present facilities, performance data collection should be relocated to an area in which sufficient numbers of experimental observers are available. Collaborative efforts with faculty members at the University of Hawaii should provide the opportunity to establish an on-campus test facility.

3. Magnification of distant targets in video images substantially enhances an observer's ability to rapidly detect and recognize them. For this reason, some form of adjustable magnification should be provided to remote teleoperators in order to support reconnaissance operations. The findings of this study are most directly applicable to a stationary viewing platform. They should not be taken to be indicative of the performance of more dynamic, interactive tasks such as driving a vehicle by remote control.

4. Though the pattern of results was less clear than was the case with magnification, extending camera interaxial separation increases the range in which stereo cues to depth and distance are operative. It also helps to compensate some of the resolution loss inherent in TV-viewing, as opposed to direct-viewing, situations. In general, stereo is less advantageous for detecting and recognizing targets at higher magnifications, but having a target zoomed-in at high magnification presumes some knowledge of the areas in which it is likely to appear since FOV must be diminished for any increase in magnification, given a constant display screen size. With respect to a particular sensor's FOV, stereo offers a means of comparable reconnaissance capabilities in wider FOVs, and hyperstereo enables comparable performance at yet wider FOVs.

5. More research should be conducted to investigate the interesting U-shaped relationship between camera interaxial separation and target detection time. In particular, binocular eye movements should be measured continuously under various stereo TV-viewing conditions to determine whether the obtained differences were a result of oculomotor adjustment times.

6. Regardless of the possibly objectionable aesthetic quality of stereo images produced by nonnormal combinations of interaxial separation and magnification, no evidence was produced in Experiment Three which suggested an interactive effect of these two factors on target detection and recognition. Therefore teleoperators which are equipped with adjustments for both camera interaxial separation and image magnification should prove effective in field

reconnaissance work. Again these findings are most directly applicable to static reconnaissance and probably do not generalize to more dynamic tasks such as vehicle driving.

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APPENDIX A

MEDICAL HISTORY FORM
(Please Print)

Please complete this form as completely and as accurately as possible. The information you provide is needed so we can better evaluate your vision. INFORMATION WHICH YOU PROVIDE WILL BE KEPT CONFIDENTIAL.

FULL NAME ______________________ AGE ___ SEX ______ DATE ____________

Are you having any special or vision problems at this time?
NO YES (circle one)
If YES, explain

Have you had any vision problems in the past? NO YES
If yes, explain:

Are you currently taking any medications? NO YES
If YES, please list them:

MEDICATION	FOR WHAT CONDITION	DOSAGE/HOW OFTEN TAKEN

Has there been any change in your medication dosage in the past 6 months?
NO YES
If YES, please explain:

When was your last eye examination? (MONTH/YEAR) ______________________

Have you ever worn glasses? NO YES
If yes, for how many years? ________

When were you told to wear your glasses? (Check one)
ALL THE TIME _____ DISTANCE ONLY _____ NEAR ONLY _____

How long have you had your present glasses? ______________

Do you see well through them? NO YES

Have you ever worn contact lenses? NO YES

If YES, what type of lenses? (Check one)

HARD LENSES _____ SOFT LENSES _____ EXTENDED WEAR LENSES _____

How long have you had you had your present contacts? ______________

Do you see well through them? NO YES

ARE YOU BOTHERED BY ANY OF THE FOLLOWING VISION PROBLEMS?
(Circle Appropriate Response)

Blurred vision at all distances	NO	YES
Blurred vision at far distances only	NO	YES
Blurred vision at near distances only	NO	YES
Double Vision	NO	YES
Tiredness from reading	NO	YES
Itching in or around the eyes	NO	YES
Excessively teary or watery eyes	NO	YES
Redness in or around the eyes	NO	YES
Aching in or around the eyes	NO	YES
Burning in or around the eyes	NO	YES
Pain in or around the eyes	NO	YES
Sensitivity to bright lights	NO	YES
Seeing black floating spots	NO	YES
Seeing flashing lights	NO	YES
Seeing halos around lights	NO	YES
Momentary loss of vision	NO	YES

HAVE YOU HAD ANY OF THE FOLLOWING EYE PROBLEMS?
(Circle Appropriate Response)

Amblyopia (Lazy Eye)	NO	YES
Cataracts	NO	YES
Detached Retina	NO	YES
Eyelid Infection	NO	YES
Glaucoma	NO	YES
Ocular Allergies	NO	YES
Strabismus (cross-eyedness) with eye turning in	NO	YES
Strabismus with eye turning out	NO	YES

HEADACHE HISTORY

How frequently do you have headaches? ______________________________

Where are your headaches located? ______________________________

____

What do you think may be causing any headaches you may experience? __________

____

When during the day do your headaches usually begin? (Check One)
WAKE UP WITH IT ___ LATE MORNING ___ LATE AFTERNOON ___
EARLY EVENING ___ OTHER TIMES ___ (EXPLAIN if you checked "OTHER TIMES")

____

How long do your headaches usually last? ______________________________

Do your headaches affect your ability to see? NO YES
If YES, how? ____

____

The space below is for any comments you would like to make.

APPENDIX B

ANOVA SOURCE TABLES FOR ALL EXPERIMENTAL ANALYSES

Table B-1. Experiment One ANOVA Source Table for Target Detection Times.

Source	Sum of Squares	DF	Mean Square	F	Prob.
Observers	111.85	1	111.85	336.4	<.01
Error	1.33	4	0.33		
Camera Separation	0.42	4	0.11	5.83	<.01
Error	0.29	16	0.02		

Table B-2. Experiment One ANOVA Source Table for Target Recognition Accuracy.

Source	Sum of Squares	DF	Mean Square	F	Prob.
Observers	983270.56	1	983270.56	1569.07	>.001
Error	2506.64	4	626.66		
Camera Separation	9619.84	4	2404.96	11.04	<.001
Error	3484.96	16	217.81		

Table B-3. Experiment Two ANOVA Source Table for Target Detection Times.

Source	Sum of Squares	DF	Mean Square	F	Prob.
Observers	115.40	1	115.40	4666.43	<.01
Error	0.10	4	0.02		
Magnification	3.71	3	1.24	12.19	<.05
Error	1.22	12			
Stero/Mono	0.91	1	0.91	10.26	<.05
Error	0.35	4	0.09		
Mag. X S/M	0.56	3	0.19	4.35	.09
Error	0.51	12	0.43		

Table B-4. Experiment Two ANOVA Source Table for Target Recognition Rates.

Source	Sum of Squares	DF	Mean Square	F	Prob.
Observers	58064.40	1	58064.40	1270.64	<.01
Error	182.79	4	45.70		
Stero/Mono	772.50	1	772.50	26.71	<.01
Error	108.19	4			
Magnification	1898.90	3	632.97	56.20	<.01
Error	135.16	12	11.26		
Mag. X S/M Int.	351.80	3	117.27	12.82	<.01
Error	0.51	12	0.43		

Table B-5. Experiment Three ANOVA Source Table for Target Detection Times.

Source	Sum of Squares	DF	Mean Square	F	Prob.
Observers	305.39	1	305.39	1303.3	>.01
Error	1.17	6	0.23		
Magnification	14.07	3	4.69	20.0	>.01
Error	3.52	15	0.23		
Camera Separation	0.82	4	0.21	3.41	>.05
Error	1.20	20	0.06	3.41	>.05
Mag. X Cam. Sep.	1.09	12	0.09	1.92	.169
Error	2.83	60	0.05		

Table B-6. Experiment Three ANOVA Source Table for Target Recognition Rates.

Source	Sum of Squares	DF	Mean Square	F	Prob.
Observers	12590.70	1	12590.70	1387.6	<.01
Error	54.44	6	9.07		
Magnification	31.16	3	110.39	71.1	<.01
Error	27.94	18	1.55		
Camera Separation	48.19	4	12.05	19.4	<.01
Error	14.91	24	0.62		
Mag. X Cam. Sep.	59.77	12	4.98	4.1	<.05
Error					

END
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